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THE CALIFORNIA EARTHQUAKE.

THREE days after the earthquake of April 18, Governor Pardee appointed a committee of inquiry consisting of Professor A. C. Lawson, of the State University; Mr. G. K. Gilbert, of the U. S. Geological Survey; Professor Fielding Reid, of Johns Hopkins University; Professor J. C. Branner, of Stanford University; Professor A. O. Leuschner, of the State University; Professor George Davidson, of the State University; Professor Charles Burekhalter, of the Chabot Observatory, and Professor William Wallace Campbell, director of the Lick Observatory. Professor Lawson was elected chairman and Professor Leuschner secretary. The results of the inquiry communicated to Governor Pardee on May 31, are as follows:

One of the remarkable features of the Coast Ranges of California is a line of peculiar geomorphic expression which extends obliquely across the entire width of the mountainous belt from Mendocino County to Riverside County. The peculiarity of the surface features along this line lies in the fact that they are not due, as nearly all the other features of the mountains are, to atmospheric and stream erosion of the uplifted mass which constitutes the mountains, but have been formed by a dislocation of the earth's crust, or rather a series of such dislocations, in time past, with a differential movement of the parts on either side of the plane of rupture. In general this line follows a system of long narrow valleys, or where it passes through wide valleys it lies close to the base of the

confining hills, and these have a very straight trend; in some places, however, it passes over mountain ridges, usually, at the divide separating the ends of two valleys; it even in some cases goes over a spur or shoulder of a mountain. Along this line are very commonly found abrupt changes in the normal slope of the valley sides giving rise to what are technically known as scarps. These scarps have the appearance of low precipitous walls which have been usually softened and rounded somewhat by the action of the weather. Small basins or ponds, many having no outlet, and some containing saline water, are of fairly frequent occurrence and they usually lie at the base of the small scarps. Trough-like depressions also occur bounded on both sides by scarps. These troughs and basins can only be explained as due to an actual subsidence of the ground or to an uplift of the ground on one side or the other, or on both sides. The scarps similarly can only be ascribed to a rupture of the earth with a relative vertical displacement along the rupture plane. Frequently small knolls or sharp little ridges are found to characterize this line and these are bounded on one side by a softened scarp and separated from the normal slope of the valley side by a line of depression. In many cases these features have been so modified and toned down by atmospheric attack that only the expert eye can recognize their abnormal character; but where their line traverses the more desert parts of the Coast Range, as for example in the Carissa Plains, they are well known to the people of the country and the aggregate of the features is commonly referred to as the 'earthquake crack.'

This line begins on the north at the mouth of Alder Creek near Point Arena and extends southeasterly nearly parallel with the coast line to a point about two miles below Fort Ross, a distance of forty-

three miles. Here it passes outside of the shore line and is again met with at the point where Bodega Head joins the mainland. Thence it appears to continue southward through Tomales Bay and Bolinas Lagoon. Beyond Bolinas Lagoon it passes outside of the Golden Gate and enters the shore again at Mussel Rock, eight miles south of the Cliff House. From this point it is traceable continuously along the valley line occupied by San Andreas and Crystal Springs Lakes, past Woodside and Portola, over a saddle back of Black Mountain, thence along Stevens Creek Cañon, passing to the southwest of Table Mountain and Congress Springs to the vicinity of Wrights, on the narrow-gauge railway between San José and Santa Cruz. From Wrights it continues on in the same course through the Santa Cruz Mountains to the point where the Southern Pacific Railway crosses the Pajaro River near Chittenden. From the crossing of the Pajaro the line extends up the valley of the San Benito River, across the eastern portion of Monterey County, and thence follows the northeastern side of the valley of the San Juan River and the Carissa Plains to the vicinity of Mount Pinos, in Ventura County. The line thus traced from Point Arena to Mount Pinos has a length of 375 miles, is remarkably straight, and cuts obliquely across the entire breadth of the Coast Ranges. To the south of Mount Pinos the line either bends to the eastward following the general curvature of the ranges or is paralleled by a similar line offset from it *en echelon*; for similar features are reported at the Tejon Pass and traceable thence though less continuously across the Mojave Desert to Cajon Pass and beyond this to San Jacinto and the southeast border of the Colorado Desert. The probability is that there are two such lines, and that the main line traced from Point Arena to Mount Pinos is continued with

the same general straight trend past San Fernando and along the base of the remarkably even fault scarp at the foot of which lies Lake Elsinore. But, leaving the southern extension of the line out of consideration as somewhat debatable, we have a very remarkable physiographic line extending from Point Arena to Mount Pinos which affords every evidence of having been in past time a rift, or line of dislocation, of the earth's crust and of recurrent differential movement along the plane of rupture. The movements which have taken place along this line extend far back into the Quaternary period, as indicated by the major, well degraded fault scarps and their associated valleys; but they have also occurred in quite recent times, as is indicated by the minor and still undegraded scarps. Probably every movement on this line produced an earthquake, the severity of which was proportionate to the amount of movement.

The cause of these movements in general terms is that stresses are generated in the earth's crust which accumulate till they exceed the strength of the rocks composing the crust and they find a relief in a sudden rupture. This establishes the plane of dislocation in the first instance, and in future movements the stresses have only to accumulate to the point of overcoming the friction on that plane and any cementation that may have been effected in the intervals between movements.

The earthquake of the eighteenth of April, 1906, was due to one of these movements. The extent of the rift upon which the movement of that date took place is at the time of writing not fully known. It is, however, known from direct field observations that it extends certainly from the mouth of Alder Creek near Point Arena to the vicinity of San Juan in San Benito County, a distance of about 185 miles. The destruction at Petrolia and Ferndale

in Humboldt County indicates that the movement on the rift extended at least as far as Cape Mendocino, though whether the rift lies inland or offshore remains as yet a matter of inquiry. Adding the inferred extension of the movement to its observed extent gives us a total length of about three hundred miles. The general trend of this line is about N. 35° W., but in Sonoma and Mendocino counties it appears to have a slight concavity to the northeast, and if this curvature be maintained in its path beneath the waters of the Pacific it would pass very close to and possibly inside of Capes Gordo and Mendocino. Along the 185 miles of this rift where movement has actually been observed the displacement has been chiefly horizontal on a nearly vertical plane, and the country to the southwest of the rift has moved northwesterly relatively to the country on the northeast of the rift. By this it is not intended to imply that the northeast side was passive and the southwest side active in the movement. Most probably the two sides moved in opposite directions. The evidence of the rupture and of the differential movement along the line of rift is very clear and unequivocal. The surface soil presents a continuous furrow generally several feet wide with transverse cracks which show very plainly the effort of torsion within the zone of the movement. All fences, roads, stream courses, pipe lines, dams, conduits and property lines which cross the rift are dislocated. The amount of dislocation varies. In several instances observed it does not exceed six feet. A more common measurement is eight to ten feet. In some cases as much as fifteen or sixteen feet of horizontal displacement has been observed, while in one case a roadway was found to have been differentially moved twenty feet. Probably the mean value for the amount of horizontal displacement along the rift line is about ten feet and the variations

from this are due to local causes such as drag of the mantle of soil upon the rocks, or the excessive movement of soft incoherent deposits. Besides this general horizontal displacement of about ten feet there is observable in Sonoma and Mendocino counties a differential vertical movement not exceeding four feet, so far as at present known, whereby the southwest side of the rift was raised relatively to the northeast side, so as to present a low scarp facing the northeast. This vertical movement diminishes to the southeast along the rift line and in San Mateo County is scarcely if at all observable. Still farther south there are suggestions that this movement may have been in the reverse direction, but this needs further field study.

As a consequence of the movement it is probable that the latitudes and longitudes of all points in the Coast Ranges have been permanently changed a few feet, and that the stations occupied by the Coast and Geodetic Survey in their triangulation work have been changed in position. It is hoped that a reoccupation of some of these stations by the Coast and Geodetic Survey may contribute data to the final estimate of the amount of movement.

The great length of the rift upon which movement has occurred makes this earthquake unique. Such length implies great depth of rupture, and the study of the question of depth will, it is believed, contribute much to current geophysical conceptions.

The time of the beginning of the earthquake as recorded in the Observatory at Berkeley was 5^h 12^m 6^s A.M., Pacific standard time. The end of the shock was 5^h 13^m 11^s A.M., the duration being 1^m 5^s. Within an hour of the main shock twelve minor shocks were observed by Mr. S. Albrecht of the Observatory and their time accurately noted. Before 6^h 52^m P.M. of the same day thirty-one shocks were noted

in addition to the main disturbance. These minor shocks continued for many days after April 18, and in this respect the earthquake accords in behavior with other notable earthquakes in the past. The minor shocks which succeed the main one are interpreted generally as due to subordinate adjustments of the earth's crust in the tendency to reach equilibrium after the chief movement.

The collection of time records necessarily proceeds slowly. The purpose of the coseismic curves based upon these records is in general two-fold. In ordinary earthquakes it is one of the means of locating the seat of the disturbance when there is no surface manifestation of the rupture in the earth's crust. In the present instance, however, the rupture has declared itself in an unmistakable rift observable at the surface, and coseismals are, therefore, unnecessary for the determination of this important factor in the general problem, so far at least as regards the main disturbance. It is probable, however, that so radical a change in the equilibrium of the stresses of the earth's crust would induce secondary ruptures and consequently secondary earthquakes closely associated with the chief shock. The careful plotting of the time records may, therefore, be useful in revealing the location of these secondary disturbances, such for example as the one which affected southern California on the afternoon of the eighteenth of April. The second purpose of securing time records is the determination of the velocity of propagation of the earth wave; and the data for this which are likely to be most serviceable are the records obtained at various quite distant seismographic stations.

The destructive effects of the earthquake are in the main distributed with reference to the line of rift. The exact limits of the area of destruction have not yet been mapped, but it is known to extend out

about twenty-five or possibly thirty miles on either side of the rift. On the southwest side the greater part of this area to the north of the Golden Gate lies in the Pacific. This area extends from Eureka, in Humboldt County, to the southern extremity of Fresno County, a distance of about four hundred miles.

Beyond this area of destructive shock the earthquake was felt in its milder manifestations over a wide territory. Our reports to date show that it was felt in Oregon as far north as Coos Bay and on the south as far as Los Angeles. To the east it was felt over the greater part of middle California and eastern Nevada, particularly along the eastern flank of the Sierra Nevada. It was felt at Lovelocks, and we have unconfirmed reports of its having been felt at Winnemucca. Far beyond the region within which it was apparent to the senses, however, the earth wave was propagated both through the earth and around its periphery; and some of the most valuable and most accurate records of the disturbance which we have are those which were registered at such distant seismographic stations as Washington, D. C.; Sitka, Alaska; Potsdam, Germany; and Tokyo, Japan.

Within the area of destructive effects approximately four hundred by fifty miles in extent the intensity varied greatly. There was a maximum immediately on the rift line. Water pipes, conduits and bridges crossing this line were rent asunder. Trees were uprooted and thrown to the ground in large numbers. Some trees were snapped off, leaving their stumps standing, and others were split from the roots up. Buildings and other structures were in general violently thrown and otherwise wrecked, though some escaped with but slight damage. Fissures opened in the earth and closed again, and in one case reported a cow was engulfed. A second line

of maximum destruction lies along the floor of the valley system of which the Bay of San Francisco is the most notable feature, and particularly in the Santa Rosa and Santa Clara valleys. Santa Rosa, situated twenty miles from the rift, was the most severely shaken town in the state and suffered the greatest disaster relatively to its population and extent. Healdsburg suffered to a nearly similar degree. San José, situated thirteen miles, and Agnews, about twelve miles from the rift, are next in the order of severity. Stanford University, seven miles from the rift, is probably to be placed in the same category. All of these places are situated on the valley floor and are underlain to a considerable depth by loose or but slightly coherent geological formations, and their position strongly suggests that the earth waves as propagated by such formations are much more destructive than the waves which are propagated by the firmer and highly elastic rocks of the adjoining hill lands. This suggestion is supported by a consideration of the destructive effects exhibited by towns and single buildings along the same valley line which are situated wholly or partly on rock. Petaluma and San Rafael, though nearer the rift than Santa Rosa, suffered notably less, and they are for the most part on, or close to, the rocky surface. The portions of Berkeley and Oakland which are situated on the alluvial slope suffered more than the foothills, where the buildings are founded on rock. The same suggestion is further supported from a consideration of the zone of maximum destructive effect on the southwest side of the rift. This zone lies in the Salinas Valley. The intensity of destructive action at Salinas was about the same as at San José, and the town is situated on the flood plain deposits of the Salinas River. Along the banks of the Salinas River and extending from Salinas to the vicinity of

Gonzales, so far as our reports at present show, the bottom lands were more severely ruptured, fissured and otherwise deformed than in any other portion of the state. The Spreckels Sugar Mill, situated on the banks of the river, suffered more severely probably than any other steel structure in the state. Santa Cruz, on the other hand, which is on the same side of the rift, and at the same distance from it, but which is built on rock for the most part, suffered much less damage. In the northern counties along the coast the most severe effects were felt at Ferndale, on the south margin of the flood plain of the Eel River, and at Petrolia, on the bottom land of the Mattole. Fort Bragg was severely shaken with very destructive effects, but our reports do not yet indicate the character of the ground upon which it is situated.

In the facts which have been cited we seem to have warrant for a generalization as to the excessively destructive effect of the earth wave as transmitted by the little coherent formations of the valley bottoms. But it must be borne in mind that by far the greater number of structures subject to destructive shock are situated in the valley lands and that there has not yet been time for a detailed comparison of the effects in the valleys with those in the hills, where the buildings are founded on firm rock except in a few notable instances.

The most instructive of these instances is the city of San Francisco, and the facts observed there are entirely in harmony with the generalization above outlined. In the city of San Francisco we may recognize for preliminary purposes four types of ground: (1) The rocky hill slopes; (2) the valleys between the spurs of the hills which have been filled in slowly by natural processes; (3) the sand dunes; (4) the artificially filled land on the fringe of the city. Throughout the city we have a graded scale of intensity of destructive effects

which corresponds closely to this classification of the ground. The most violent destruction of buildings, as everybody knows, was on the made ground. This ground seems to have behaved during the earthquake very much in the same way as jelly in a bowl, or as a semi-liquid material in a tank. The earth waves which pass through the highly elastic rocks swiftly with a small amplitude seem in this material to have been transformed into slow undulations of great amplitude which were excessively destructive. The filled in material and the swampy foundation upon which it rests behaved, in other words, as a mass superimposed upon the earth's surface, rather than as a part of the elastic crust itself. In a less degree the same thing is true of the sand dune areas, where the ground was frequently deformed and fissured. In still less degree the naturally filled valleys between the hill spurs were susceptible to this kind of movement, and the destruction of buildings was correspondingly less, but still severe, depending very largely on the character of the buildings, the integrity of their construction, etc. In portions of these valleys, however, the original surface of the ground has been modified by grading and filling, and on the filled areas the destruction was more thorough than elsewhere in the same valley tracts. On the rocky slopes and ridge tops, where, for the most part, the vibration communicated to buildings was that of the elastic underlying rocks, the destruction was at a minimum. On some of the hills chimneys fell very generally and walls were cracked; on others even the chimneys withstood the shock.

While this correlation of intensity of destructive effect appears to hold as a generalization, there are well known exceptions which find their explanation in the strength of the structures. Modern class A steel structures with deep foundations appear to

have been relatively passive, while the made ground in their immediate vicinity was profoundly disturbed. Thoroughly bonded and well cemented brick structures, on similarly deep and solid foundations, seem to have been equally competent to withstand the shock, except for occasional pier-like walls not well tied to the rest of the building. The weak points in wooden frame structures were in general the faulty underpinning and lack of bracing, and chimneys entirely unadapted to resist such shocks. With these faults corrected, frame buildings of honest construction would suffer little damage beyond cracking of plaster in such a shock as the eighteenth of April, save on the made ground, where deep foundations and large mass appear to be essential for the necessary degree of passivity.

Pipe lines and bridges crossing the rift line present a peculiar, if not quite unique, engineering problem which will doubtless be solved in the near future. Pipe lines on low swampy ground or in made ground are in much greater danger of destruction from earthquake shocks than those on high ground underlaid by rock, except in the immediate vicinity of the rift, where nothing could be constructed which would withstand the violence of the earth movement.

One of the lessons of the earthquake which seems peculiarly impressive is the necessity for studying carefully the site of proposed costly public buildings where large numbers of people are likely to be congregated. In so far as possible such sites should be selected on slopes upon which sound rock foundation can be reached. It is probably in large measure due to the fact of their having such a rock foundation that the buildings of the State University, at Berkeley, escaped practically uninjured. The construction of such buildings as our public schools demands the most earnest attention of the people and of the

authorities charged with their construction. A great many of our schools proved to be of flimsy construction and ill adapted to meet the emergency of an earthquake shock of even less severity than that of the eighteenth of April.

The commission in presenting this brief report has had in mind the demand on the part of the people of the state and of the world at large for reliable information as to the essential facts of the earthquake. It has, therefore, not presumed to engage in any discussion of the more abstruse geological questions which the event naturally raises. It leaves such discussion for a more exhaustive report which can only be prepared after the campaign of data collection is complete, and that may be some months hence.

Very respectfully submitted in behalf of the commission.

ANDREW C. LAWSON,
Chairman.

A. O. LEUSCHNER,
Secretary.

THE ROYAL SOCIETY OF CANADA.

THE twenty-fifth annual meeting of the Royal Society of Canada was held in Ottawa, Ontario, from Tuesday to Thursday evening, May 22-24, under the presidency of Dr. Alexander Johnson, M.A., LL.D., D.C.L., emeritus professor of mathematics in McGill University, Montreal. There was a large attendance of fellows. This society, which is of a distinctive national character, comprises four sections, each numbering thirty members or fellows selected and elected from any of the provinces of the Dominion of Canada. Section I. and Section II. are more distinctively literary and historical and comprise French and English writers, while Section III. and Section IV., devoted to the mathematical, physical and chemical sciences, as well as to the geological and biological sciences,